

TN 295

.U4

No. 9124





Bureau of Mines Information Circular/1987

Mined Land Subsidence Impacts on Farmland With Potential Application to Illinois: A Literature Review

By David L. Veith



UNITED STATES DEPARTMENT OF THE INTERIOR

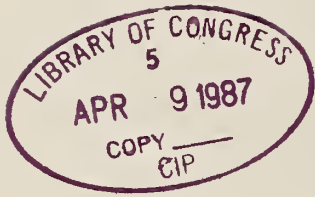
Mined Land Subsidence Impacts on Farmland With Potential Application to Illinois: A Literature Review

By David L. Veith



UNITED STATES DEPARTMENT OF THE INTERIOR
Donald Paul Hodel, Secretary

BUREAU OF MINES
Robert C. Horton, Director



TN295
.U4
no. 9124

Library of Congress Cataloging in Publication Data:

Veith, David L.

Mined land subsidence impacts on farmland with potential application to Illinois.

(Information circular ; 9124)

Bibliography: p. 15-16.

Supt. of Docs. no.: I 28.27: 9124.

1. Subsidence (Earth movements)—Illinois. 2. Coal mines and mining—Illinois.
3. Land use—Illinois. 4. Farms—Illinois. I. Title. II. Series: Information circular (United States. Bureau of Mines) ; 9124.

TN295.U43 [QE600.3.U6] 622 s [333.76'16] 86-600227

CONTENTS

	<u>Page</u>
Abstract.....	1
Introduction.....	2
Geological and land considerations.....	3
Geology of the Illinois Basin.....	3
Drainage classes of soils.....	3
Land use qualifications.....	4
Subsidence characteristics.....	6
High-extraction mining.....	6
Illinois mining.....	7
Ground settlements of high-extraction mining.....	8
Subsidence effects.....	9
Western Pennsylvania ground water.....	9
Illinois ground water.....	10
Farmlands.....	10
Crops.....	11
Economic considerations.....	12
Bureau of Mines and State of Illinois subsidence research program.....	13
Summary and conclusions.....	14
References.....	15

ILLUSTRATIONS

1. Drainage classes of soils.....	4
2. Optimized high-extraction underground coal mining plan.....	7
3. Typical subsidence from single-panel high-extraction mining in western Pennsylvania.....	10

TABLES

1. Crop yields on three Virgin Island soil types with slope and erosion, with average to high levels of management.....	5
2. Development of underground coal mining techniques in Illinois.....	7

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot	pct	percent
in	inch	st	short ton
m ²	square meter	vol pct	volume percent
mi ²	square mile	yr	year
mm	millimeter	°	degree

MINED LAND SUBSIDENCE IMPACTS ON FARMLAND WITH POTENTIAL APPLICATION TO ILLINOIS: A LITERATURE REVIEW

By David L. Veith¹

ABSTRACT

This report summarizes a Bureau of Mines review of selected literature on the effects of subsidence due to high-extraction underground coal mining on farmland areas. The data are presented for consideration in evaluating the subsidence effects due to similar mining techniques on the prime farmland areas of Illinois.

In Illinois the ground water level in the glacial drift is only 2 to 15 ft below the nearly flat to gently rolling ground surface. The main subsidence concern is flooding, as caused by the lowering of the ground surface, and the subsequent effects on crop production. Positive drainage must be maintained in the farmlands, and the need exists for extensive regional planning by the mining and agricultural industries to maximize short- and long-term production from both efforts. The Bureau is cooperating with the State of Illinois to develop basic information necessary for such planning.

¹Mining engineer, Twin Cities Research Center, Bureau of Mines, Minneapolis, MN.

INTRODUCTION

This report summarizes selected literature dealing with underground mine-related subsidence effects on coal mining lands throughout the United States. Some foreign data are also summarized. The information is presented for consideration in the evaluation of subsidence effects on Illinois prime farmland crop production, but in no way is it implied that the information pertains directly to Illinois unless the reference is clearly identified as such.

As will be illustrated, the effects of underground coal mining subsidence in Illinois have been investigated for some time, but no formal study of the effects on prime farmland crop production have been conducted. Efforts underway at this time will document such impacts and lead to mitigative measures that should optimize production from both the underground coal mining industry and the agricultural industry.

Much of central and southern Illinois prime farmland overlies high-quality bituminous coal seams. Maximization of underground coal production results in ground movements and subsequent disturbance of the surface. Illinois ground water lies 2 to 15 ft below the ground surface, and subsidence-induced ground movements can also affect the movement of surface water. The ground water is generally dependent on precipitation to maintain its level and, therefore, its availability for crop production. Any modification of surface water hydrology could affect the resultant crop production.

The challenge is to maximize underground coal recovery in these Illinois prime farmland areas, and at the same time ensure the productivity levels of crops grown on the overlying soils. The solution lies in the cooperation of these two valuable industries to develop planned mining and agriculture programs to maximize recovery from both natural resources. To acquire the in-depth understanding necessary to achieve this goal, the Bureau of Mines and the State of Illinois are cooperating on a

coordinated mine subsidence research program to ultimately develop guidelines for more effective underground mining techniques in order to maximize coal extraction while preserving the productivity of prime farmlands.

Illinois coal mining companies have basically three options for underground operations (1):²

1. Mine a low percentage of the coal and leave substantial pillars for total support of the overlying strata (low extraction).

2. Mine a high percentage of the coal, plan on subsidence, and take the responsibility for reclamation of the affected surface (high extraction).

3. Mine no coal at all (no extraction).

Obviously there are certain circumstances under which each of the three options would be the best choice. When considering maximum utilization of both the coal resource and the overlying prime farmland resource, option 2 is the best choice (1). High-extraction underground coal mining, planned in advance to minimize surface impacts on the overlying agriculture industry, and properly carried out, will result in the maximum utilization of both resources.

In 1982, Peabody Coal Co. reported that 193 subsidence events had occurred on its Illinois properties since 1971 (1). Less than 2 pct of its mined lands were affected. Subsidence regulation proposed at that time would have caused the company to lose about 70 million st of coal reserves (about 8 pct of their total reserves), and would have shortened their mining life by more than 42 yr, or more than 190-mine yr of production. Regulation that reduces mineable reserves because of potential subsidence impacts is, therefore, of great concern to mining companies such as Peabody. Research to improve the

²Underlined numbers in parentheses refer to items in the list of references at the end of this report.

cohabitation of the mining and agricultural industries in the prime farmland areas of Illinois is also of great

interest to the involved mining companies, the agricultural industry, and both State and Federal governmental agencies.

GEOLOGICAL AND LAND CONSIDERATIONS

GEOLOGY OF THE ILLINOIS BASIN (2)

Overall, the Illinois Basin is a broad, spoon-shaped trough of sediments containing several anticlinal belts. Generally, the folds have gentle slopes with less than 200 ft of relief. Folding and faulting is most prominent in southeastern Illinois. The topography ranges from flat-lying to rolling, with soils chiefly developed in glacial drift. Till deposits in the northern and central parts of the State reach 600 ft in depth, but the drift is generally less than 50-ft deep in southern Illinois.

Almost all the mapped coal reserves in Illinois are in the middle portion of the Pennsylvanian System, which underlies about 70 pct of the land of the State. Shales and underclays form 65 to 70 pct of the upper portions of the System, limestones form 5 to 10 pct, and coal 1 to 2 pct. Shale beds exceed 100 ft in thickness but more commonly are 20-to-40 ft thick, and the underclays are commonly 2- to 5-ft thick. The Pennsylvanian sequence shows great lateral persistence, except for the sandstones, which frequently occur as channel deposits.

DRAINAGE CLASSES OF SOILS (3)

It is important in the study of the effects of mine subsidence on prime farmland to understand the drainage classes of soils and how these affect crop production. This understanding is particularly important in Illinois where ground water is shallow and essentially contained in glacial overburden, supported by shale overlying the coal seams.

Figure 1 depicts the five U.S. Department of Agriculture (USDA) (4) drainage classes of soils and indicates approximate root penetration with respect to the mottled zone in each class. A mottled zone contains spots of different colors in a uniform soil matrix, indicating

intermittent wetness with associated oxidized and reduced materials.

In well-drained soils the moisture is rapidly removed by internal drainage. These soils often are dry because they are close to bedrock, are on very steep slopes, or have coarse textures that limit the moisture holding capacity.

In moderately well drained soils the water is removed less rapidly than in well-drained soils, so that the profile is occasionally wet for short but significant periods. These soils usually have low-permeability layers in the B or C horizons, and accumulations of seasonal seepage waters.

Somewhat poorly drained soils are wet for significant periods but not continuously, as water is removed slowly. These soils have a low-permeability layer, a high water table, and accumulate water through seepage.

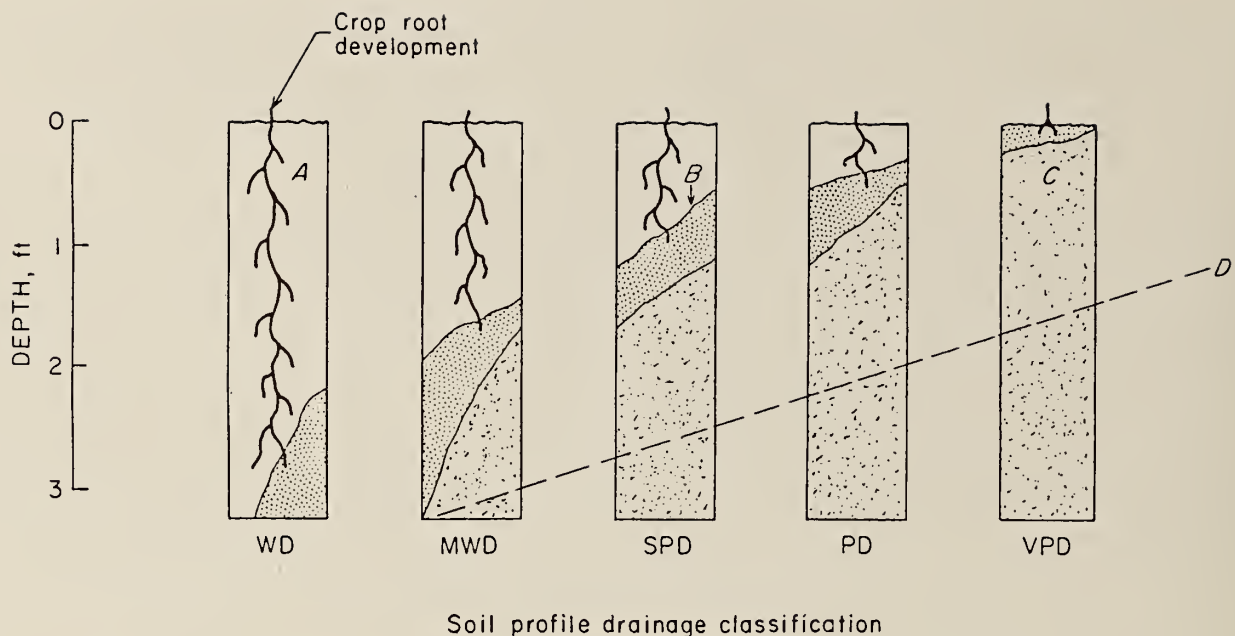
Poorly drained soils remain wet much of the year because water is removed very slowly. The water table is near the surface much of the year; there is a low permeability layer, and seepage is a problem.

Finally, very poorly drained soils are continuously wet, as the water table is near the surface most of the year. These soils are in depressions and ponding sites where water accumulates.

According to the USDA, the rooting zone basically stops at the mottled zone, and the depth of this zone determines crop production. Changes in surface elevation with respect to the ground water elevation may change the location of the mottled zone, and, therefore, the crop production capacity of the soil.

If wet soils are permeable, they can be improved. When wet soils are only slightly permeable, drainage and amelioration are often difficult and productivity improvement may only be slight.

Olson (3) analyzed information from another USDA rating of soils for plant



<u>Drainage class designation</u>	<u>Zone designation</u>
WD - Well drained	A - Rooting zone
MWD - Moderately well drained	B - Mottled zone
SPD - Somewhat poorly drained	C - Gray, brown, or stained zone
PD - Poorly drained	D - Permanent or fluctuating water table (inferred from C zone characteristics)
VPD - Very poorly drained	

FIGURE 1.—Drainage classes of soils. After Olson (3).

growth (5). Good plant growth requires well-drained to moderately well drained soil, with very friable to friable, moist consistency. Textures can be very fine sandy loam, fine sandy loam, loam, silt, or silt loam. The thickness of the soil above a hard layer, water table, or bed-rock must be more than 30 in. Finally, the soil slope must be less than 8 pct, and it must contain less than 8 vol pct coarse fragments. Fragments are considered coarse depending on their shape and dimensions. Granular and crumb structures are coarse if their particle diameter ranges from 5 to 10 mm, and angular to subangular blocky structures are coarse if their particle diameter ranges from 50 to 100 mm.

LAND USE QUALIFICATIONS

Olson (3) describes some physical characteristics of Tompkins County, NY, soils related to land use. Some of these characteristics can be identified with subsidence effects and, therefore, may have some application to Illinois. The county soil map shows that--

1. More than 75 pct of active pasture and cropland have slopes of less than 10 pct.
2. About 80 pct of abandoned farmland has slopes of more than 10 pct.
3. About 40 pct of forest land has slopes of 35 to 70 pct.

4. About 75 pct of pasture land has soils with seasonal water tables more than 5 in below the surface.

5. About 60 pct of the cropland has soils of moderate to rapid permeability. Thus, it appears that the most productive soils have slopes of less than 10 pct, seasonal water tables (pasture land) more than 5 in below the surface, and moderate to rapid permeability drainage.

Erosion of soils is probably the most destructive process that reduces the productivity of the land (3). Topsoils and the A horizon generally contain the most nutrients and the best structure for plant growth, and any material eroded from these parts of the soil profile will have a detrimental effect on crop yield and plant growth.

A common agricultural tool, the Universal Soil Loss Equation, permits planners and farmers to predict the average rate of soil erosion for each feasible alternative combination of crop management related to a specific soil map unit, the rainfall pattern, and the topography. As described by Olson, (3), the Universal Soil Loss Equation is--

$$A = RKLSCP$$

where A = the computed soil loss per unit area,

R = the rainfall and runoff factor,

K = the soil erodability factor,

L = the slope length factor,

S = the slope steepness factor,

C = the cover and management factor,

and P = the support practice factor.

Soil is protected from erosion by vegetation, the design of which is determined by the slope and contour of the land. Since erosion of soils is a natural geomorphic process that can never be eliminated completely, tolerable soil

losses can be established for each soil type to balance the soil building process and thus to maintain acceptable agricultural production over a long period of time.

Olson (3) describes crop yields in the Virgin Islands for clay and clay-loam soil types of various slopes, with average and high levels of management (table 1). Obviously, slopes greater than 5 pct and erosion are detrimental to crop production, resulting in crop losses ranging from 8 to 42 pct, when compared with production from relatively flat, uneroded soils. Although probably not applicable to the prime farmlands of Illinois, this comparison is included to illustrate the potential impact of slope and erosion on crop production.

In Illinois prime farmlands, subsidence-created slopes are generally less than 1 pct but may reach 4 pct for short distances along their profile. Therefore, it appears that if subsidence from high-extraction underground coal mining creates surface slopes of less than 5 pct, the impact will not be great enough to significantly increase erosion of the soil. Erosion is not the concern in Illinois, but changes in drainage of the flat prime farmlands caused by subsidence are of concern.

Sarkar (6) identified 22 independent soil characteristics from which soil scientists attempt to correlate yields. These characteristics are representative of a broad range of soils; many are related to moisture holding capacity and thus are critical to plant growth and crop production.

TABLE 1. - Crop yields on three Virgin Island soil types with slope and erosion, with average to high levels of management

Soil type	Slope, pct	Yield, pct
Clay.....	0- 2	100
	2- 5	83- 90
	¹ 5-12	58- 89
Clay-loam 1.....	2-15	100
	¹ 5-12	75- 92
Clay-loam 2.....	0- 3	100
	5-12	75- 92

¹Eroded.

Some of Sarkar's characteristics, as described by Olson, which may have application in Illinois, follow:

1. Yields on the same field in Maryland clearly showed the effects of moisture and erosion.

2. Iowa corn yields related directly to soil variables such as slope, bio-sequence, available water holding capacity, erosion, organic carbon, drainage class, clay content, bulk density, pH, available phosphorus, and available potassium.

3. Soil factors most highly correlated with corn yields in North Carolina were moisture holding capacity, clay and sand combinations, extractable phosphorus, percent base saturation and related properties that control soil acidity, and the charge on the cation-exchange complex.

Weather and agricultural management are major variables influencing the soils and the resultant yields. Since weather cannot be controlled, agriculture practices and mining activities affecting those practices become the controlling variables. Soils determine the potential for moisture storage, which affects a soil's ability to withstand drought. Soil factors influencing runoff and erosion directly influence crop yields, and

managing mining activities such that these soil factors are not adversely affected will ensure that crop yields can be maximized with proper agricultural practices.

Olson (3) described a yield measuring procedure called sequential testing, which may be beneficial in measuring the effects of subsidence on crop production. Similar soils exhibit similar characteristics in the same geologic conditions. Sequential testing is the sampling of soils across a landscape in which the soils occupy "sequential" positions along the sampling transect. For example, soils in a humid region commonly have the same drainage sequence in similar geologic materials. By sampling the soils along a transect, soil drainage classes can be identified and the growth of moisture-sensitive vegetation can be measured at each sample point. Thus, vegetative growth can be related to the drainage class and to the soil depth to mottling and seasonal water tables.

Similar sequences can occur for soil texture, slope, pH, fertility, land use, crop growth, crop yield, and other soil and land characteristics. If experiments are run on contrasting soils, one can evaluate the effects of soil differences on crop production.

SUBSIDENCE CHARACTERISTICS

HIGH-EXTRACTION MINING

Peng (7) summarized the mechanics of surface subsidence in the Appalachian Coal Basin due to underground coal mining in a 1980 publication. In very general terms, room-and-pillar mining with full pillar extraction can result in subsidence similar to that resulting from longwall mining. The author sized the maximum caving dome height at 30 to 50 times the mining height with caving angles between 15° and 35° and an average angle of 25°. Ideally, strata overlying the coal seam above the caving zone will remain more or less intact and sag uniformly, as would a continuous beam, resulting in a symmetrical surface sag about the centerline of the single panel. Actually, strata behavior is greatly

dependent on the characteristics of its components, and the resulting sag may range from uniform to highly irregular. Multiple panels will result in overlapping subsidence profiles, skewed toward the previously mined panel.

Controlling factors of surface subsidence discussed by Peng are well known and will not be repeated here. In the discussion on the prevention of subsidence impacts the point was made that advance planning is the best method of eliminating or reducing surface ground damage. Regional planning of full-extraction operations, with complete regard for maintaining the relative position of surface contours, appears to be the best method of ensuring positive surface drainage. A hypothetical example of such a plan is shown in figure 2.

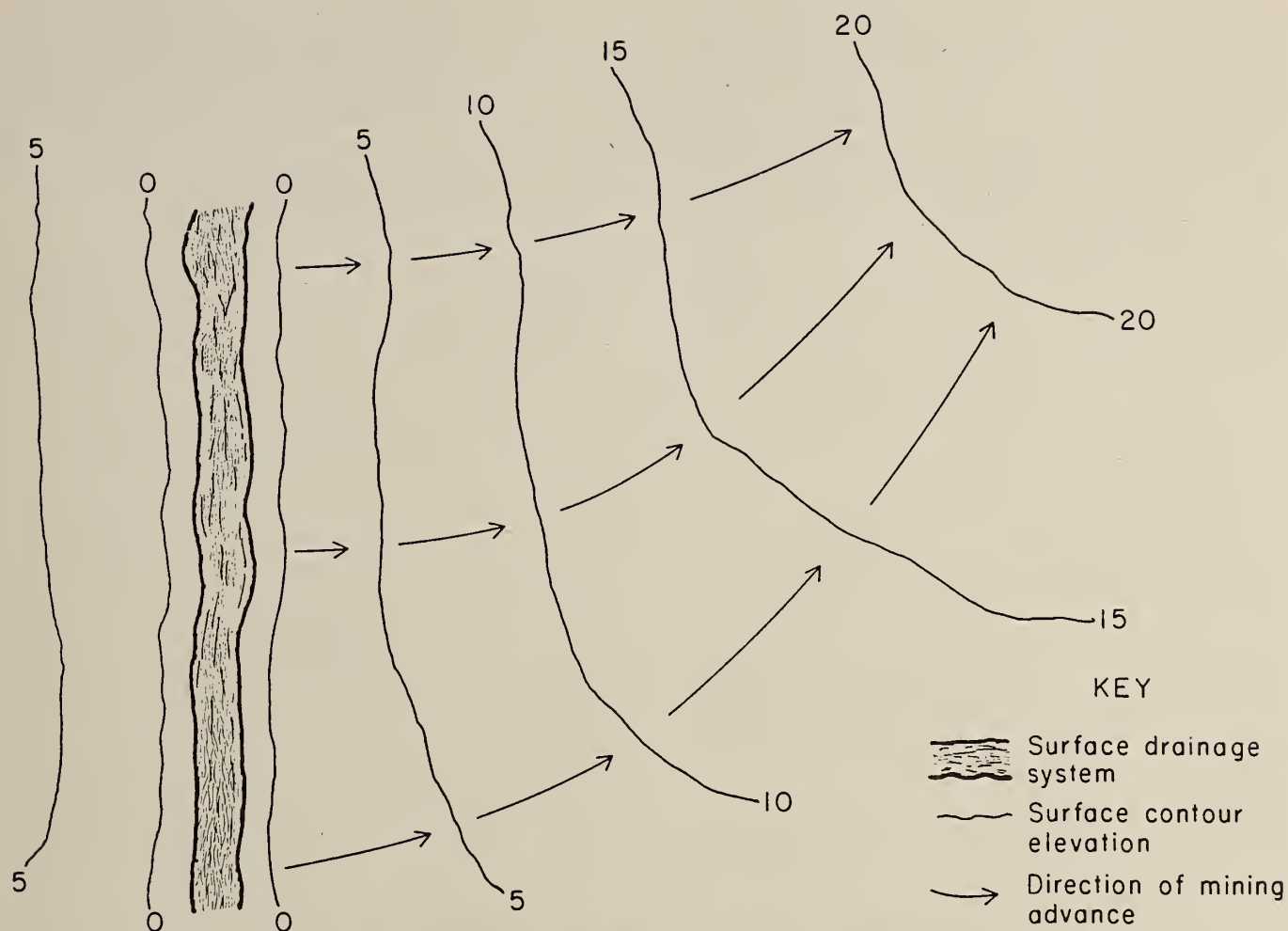


FIGURE 2.—Optimized high-extraction underground coal mining plan.

ILLINOIS MINING

Bauer (8) presented a paper in 1981 describing some of the characteristics of subsidence from various coal mining techniques in Illinois. Table 2 presents a modified list from Bauer of the progression of mining methods and the related percentages of panel extraction commonly practiced in Illinois. High-extraction retreat and longwall are the methods generally used in Illinois and are probably the methods of the future where subsidence is either desired or allowed. Where subsidence is not allowed, blind or checkerboard room-and-pillar techniques are employed.

Illinois subsidence takes two basic forms, pit subsidence and sag-trough subsidence. Pit subsidence is a sudden drop in the surface such that the hole has

nearly vertical walls. It is caused by a sudden collapse of the bedrock over a mine void, usually where the mining was close to the surface and the overlaying strata were not competent.

TABLE 2. - Progression of underground coal mining technique development in Illinois

<u>Mining method</u>	<u>Panel extraction, pct</u>
Room-and-pillar:	
Early ¹	< 80
Modified.....	< 80
Blind.....	50- 65
Checkerboard.....	40- 60
Longface.....	100
High-extraction retreat....	70- 90
Longwall.....	100
¹ If pillars pulled.	

Sag subsidence refers to a large, nearly equidimensional subsidence depression over room-and-pillar mines. Trough subsidence is similar to sag subsidence, except that the depression is elongated and typically results from high-extraction room-and-pillar and longwall mining techniques.

Data generated for Illinois by Bauer (8) indicate that pit subsidence develops only over shallow mines less than 165-ft deep. Sags or sags and troughs develop over both shallow and deep mines, and pits, sags, or troughs can develop over mines 75-to-165 ft deep.

Of the possible factors affecting the subsidence profile characteristics with a given mine geometry, the regional geology seems to have the greatest influence (8). Room-and-pillar mining in central Illinois is in the No. 5 coal seam, which is fairly thin and strong, resulting in strong pillars and low height-to-width pillar ratios and, therefore, minimal subsidence due to pillar crushing or compression.

Similar mining techniques are practiced in southwestern Illinois in the Herrin (No. 6) coal seam, which is thicker than the No. 5 seam and has some of the highest quality mine roof in the State because of well-developed, thick limestone beds overlying the coal (8). Subsidence in this region is somewhat greater than that in central Illinois.

Room-and-pillar mining in southern Illinois, also in the Herrin (No. 6) coal seam, is in an area of major regional geological structures, with little or no limestone in the mine roof (8). Subsidence is greater in this region than in the two regions described above.

In comparing subsidence in Illinois with that in Great Britain, Bauer (8) states that the angle of draw for Illinois longwall mining is 12° to 25°, which is generally less than that for British operations. Probable causes of this difference are that (1) Illinois overburden rock is stiffer and more resistant to subsurface movements, (2) British rock, unlike the rock in Illinois, has been subjected to tectonic faulting, and (3) multiple-seam mining is commonplace in Britain and not in

Illinois. Multiple-seam operations tend to break up the overburden, making it a less stiff rock mass, and thus inducing more widespread subsidence.

GROUND SETTLEMENTS OF HIGH-EXTRACTION MINING

Generally, retreat room-and-pillar and longwall mining methods are similar enough to result in similar subsidence patterns where the geology is the same (2). Longwall mining removes 100 pct of the coal within the panel; retreat room-and-pillar mining usually removes as much of the coal as local conditions allow, and when this removal is a high percentage of the in-place coal, the resulting caving and ground movement is similar to that for longwall mining of nearly equal dimensions. However, care must be exercised in this analogy, as the rock loading sequence differs greatly between the two methods.

At the Old Ben No. 24 Mine near Benton, IL, a longwall demonstration study was conducted under Bureau contract (2, 9). Three longwall panels were driven adjacent to a modified retreat room-and-pillar panel, and comparisons were made of their subsidence profiles. Longwall panel 1 was first developed adjacent to the narrow room-and-pillar panel; then, in sequence, longwall panels 2 and 3 were developed along panel 1.

Retreat room-and-pillar mining (2) at Old Ben generally recovered 80 to 90 pct of the coal; however, because of the proximity of the longwall panels, a somewhat different retreat room-and-pillar mining method was required for the demonstration section, which reduced recovery to less than 80 pct. Chain pillars about 86 ft wide separated the previously mined retreat room-and-pillar panels from longwall panel 1. The coal seam was 620-ft deep, and longwall panels 460-ft wide and 7-ft thick were mined. Maximum settlement observed was 4.3 ft over longwall panel 1 and 2.9 ft over the retreat room-and-pillar panel during the measurement period (9). Retreat room-and-pillar and longwall mining methods are considered high-extraction techniques, but their recovery factors and subsidence profiles

generally are not the same. In this case at Old Ben, with lower than normal retreat room-and-pillar mining recovery, subsidence over that operation was expected to be less than over the longwall panel. The stumps and fenders of coal left in place in the retreat room-and-pillar mining helped support the roof

and, although they were readily crushed by the overburden weight, they helped prevent the occurrence of full closure. Additionally, the proximity of the retreat room-and-pillar panel to the longwall panel was expected to skew the subsidence profile across the longwall panel. Both expectations were realized.

SUBSIDENCE EFFECTS

WESTERN PENNSYLVANIA GROUND WATER

SMC Martin Inc. (10) studied the effects of coal mine subsidence on ground water aquifers in western Pennsylvania under Bureau contract. Although the structure and hydrological regime are quite different than in Illinois, this study is still of interest in describing the effects of underground coal mine subsidence on the surface and on crop productivity.

In western Pennsylvania, deep coal mining operations often affect regional ground water supplies through subsidence and the resulting fracturing of overlying strata. The existing ground water flow system is then disrupted as it preferentially flows toward the mine workings along the newly created or widened fracture system. Additionally, more pore space is created in the strata by fracturing, so the aquifer can store more water. The water table in the vicinity of the mine becomes depressed or eliminated, thus creating a new hydrologic environment. As the rate of subsidence decreases, the fracture system begins to close due to settlement of the strata. With less direct flow paths to the mine, recharge exceeds discharge and the head increases until a new equilibrium is reached, which may or may not be the same equilibrium point as before mining, depending on the elastic properties of the strata layers.

According to SMC, longwall mining of coal in western Pennsylvania causes a zone of caving that typically forms a dome 30 to 50 times the height of mining, with the overlying strata remaining intact but subject to sagging (fig. 3). As the sag develops, a subsidence trough, or profile, is produced at the surface,

enclosing an area larger than that of the mined panel. The horizontal limits of the trough depend on the angle of draw, which includes the total area displaying subsidence effects. In western Pennsylvania the practical limit of the angle of draw is generally taken as 25° . In Illinois the subsidence pattern resulting from high-extraction mining tends to exhibit a profile with greater slopes around the inflection point than that shown in figure 3.

Maximum subsidence over a single panel occurs at the centerline, and the magnitude depends on the width of the panel, the mined seam thickness, and the vertical distance between the seam and the surface. Where the seam is flat with no adjacent panels being mined, the subsidence profile generally is symmetrical about the centerline. Multiple panels result in composite subsidence profiles as the effects overlap and are partly additive.

The response of the overlying aquifer system to longwall mining depends on site-specific variables, including depth to coal, thickness of coal removed, mining method, rock mechanics, site stratigraphy, and aquifer properties. These variables also influence the amount and degree of subsidence. Rock mechanical properties determine both the degree of fracturing in the rock units and the recompression or healing of the strata that allows water level recovery. Site stratigraphy and aquifer properties control the influence of aquitardal layers and types of aquifer systems.

To determine hydrological changes due to mining operations, it is necessary to analyze data from water level measurements, aquifer tests, and borehole geophysics, and to interpret these data

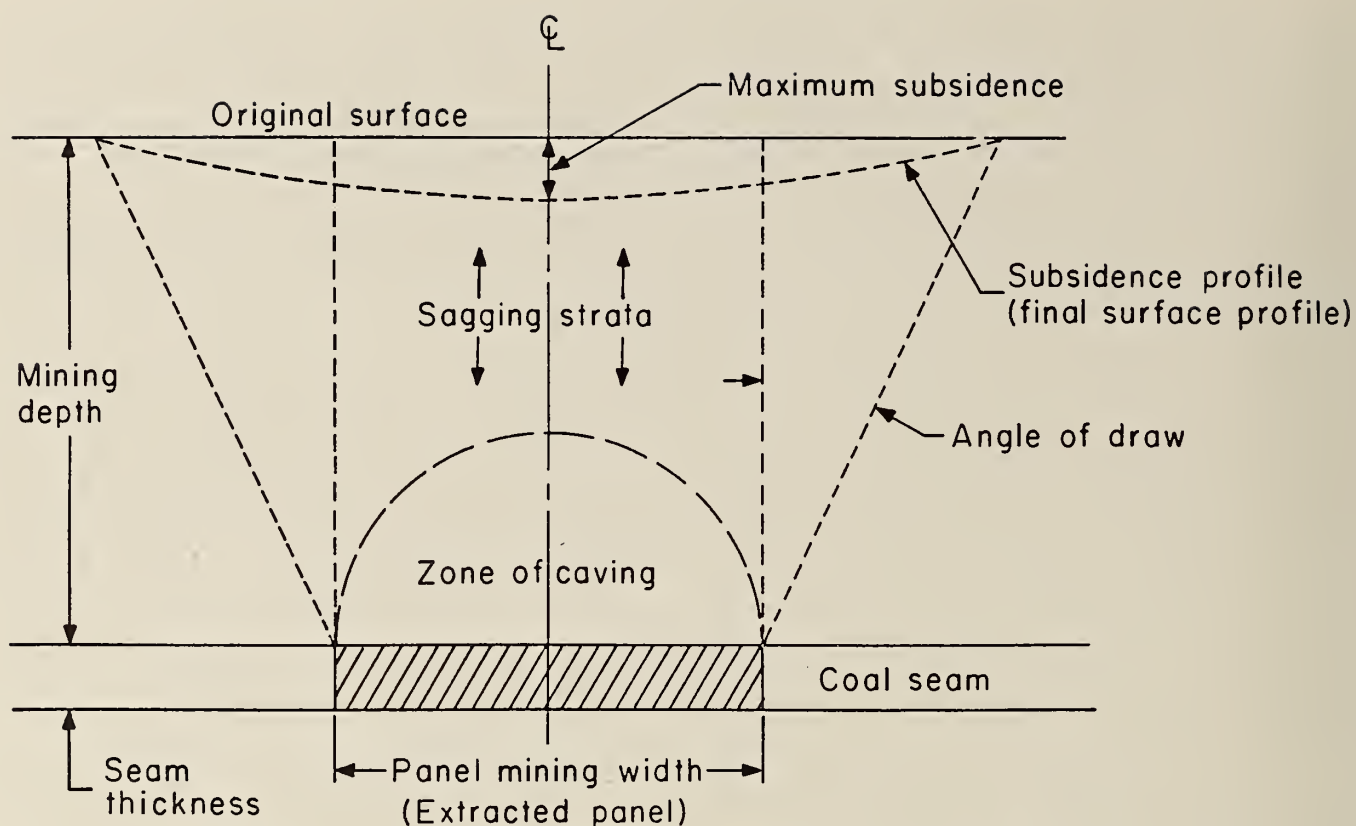


FIGURE 3.—Typical subsidence from single-panel high-extraction mining in western Pennsylvania.

by comparing premining and postmining conditions. The range of ground water fluctuations is a function of the ability of surface infiltration to reach the ground water system and of the degree of hydraulic connection between shallow aquifer zones receiving the surface infiltration and the deep aquifer zones representing the final repository of ground waters.

ILLINOIS GROUND WATER

In some instances, Illinois ground water is mainly contained in glacial overburden supported by shale strata. The shale is highly plastic and, if it is located above the caving zone over a high-extraction mining system, the entire strata should sag and settle without major fracturing. Thus, few channels may open to drain ground water to the lower strata and to the mine, and, except for a temporary depression, the ground water level should return and remain intact.

In the case of pit subsidence, generally associated with room-and-pillar mining

close to the surface, the pit walls sink along highly fractured vertical planes. Ground water thus flows more easily into the mine through channels that may take much longer to heal than those formed under sag subsidence conditions.

Deeper mining and the resulting sag or trough subsidence may have the associated problem of a depressed water table accentuated by water draining into the mine and to the clay mine floor. The clay floor absorbs moisture, weakens, and is then heaved by punching pillars. The net results are convergence of the floor and roof, more subsidence, and a greater impact on surface topography and the water table.

The reaction of ground water to subsidence in Illinois is being studied under Bureau-sponsored research, and the information will be available upon completion.

FARMLANDS (11)

The effects of mine subsidence on farmlands in general depend on the type of

crops, soil character, hydrology, topography, and other environmental factors. To evaluate such effects requires an extensive data base that does not now exist, although studies are underway. Some potential effects are--

1. Surface fissures creating paths to drain water from the topsoil, thereby causing drier surface soil conditions and erosion, which widens the cracks.

2. Changes in ground slope. Steepening slope increases flow velocity, which enhances surface runoff and erodibility. Slope reduction could lead to waterlogging and ponding of the soil and eventual crop reduction.

3. Changes in ground elevation or slope that may disrupt surface drainage and the hydraulic regime, thereby causing flooding or ponding, especially if natural topographical barriers to flow are lowered or the water table is shallow and underlain by an impermeable layer.

4. Decreases in soil fertility due to modification of the subsurface hydrology that results from downward migration of ground water through cracks.

5. Changes in ground water quality due to contact with toxic materials.

6. Occurrences of sinkholes, which may upset the normal drainage system through accumulation or loss of water.

The USDA (12) related soil erosion potential to the Universal Soil Loss Equation. It further identifies slopes ranging from "gently sloping" to "moderately sloping" as those most susceptible to water and wind erosion. These slopes are in the range of 5 to 8 pct. Slopes of 6 to 8 pct displayed gradually increasing crop losses, but the loss increased much more rapidly with steeper slopes.

Agricultural lands are classified by Guernsey (13) in relation to mine subsidence as prime and nonprime farmlands. Prime farmland has "the best combination of physical and chemical characteristics for producing food, feed, forage, fiber and oilseed crops. It is the land that gives the highest agricultural yield with minimum input when managed according to modern farming methods." Generally, prime farmland soils have slopes of less than 8 to 10 pct.

Basically, subsidence damage to agricultural lands may result in the loss of use or reduced productivity, but the extent of this effect is very site specific and, therefore, difficult to quantify in general terms. Ground movement changes the soil environment and the soil building process, and unless the movement is quite severe, it may take many years to detect the changes resulting from subsidence. As long as positive drainage is maintained and surface slopes remain gentle enough to prevent erosion beyond what is acceptable, the impact of mined land subsidence on prime farmland should be minimal (13).

CROPS

In an unpublished preliminary report on the effects of high-extraction coal-mine-induced subsidence on crop production, Darmody (14) describes the test areas in Illinois selected to compare high-extraction retreat and longwall mining methods, and the procedures used to determine the differences in results. Preliminary results indicate that longwall-caused subsidence is much more obvious than that of high-extraction retreat mining; it is more clearly marked on the surface and especially on level divides or in bottoms.

Although both types of mining make previously wet soils wetter, high-extraction retreat mining wet areas are more random and less well defined than longwall wet areas. The orientation of mining panels tends to affect the severity of subsidence effects, in that mine panels running with natural surface drainage seem to cause less impact than those running across the drainage.

A subsided panel can change the local base of a stream running across it causing ponding. This impact is greatest in areas of subtle topography, where subsidence of only a foot or two can change the drainage pattern of the entire watershed.

Weather significantly affects subsidence impacts. In a particularly wet year the subsided area may never dry sufficiently to support crop growth; however, in a dry year the subsided

surface may be able to support vegetation that normally would not survive.

A general conclusion concerning design criteria for longwall panels is that they should be oriented parallel to natural drainage patterns in areas of subtle topography to maintain positive drainage and potentially reduce surface crop damage. High-extraction retreat subsidence-induced effects, however, appear too random to generalize this type of conclusion, and more investigation is necessary to develop an innovative premine planning system to ensure acceptable drainage, as was generalized with longwall orientation.

ECONOMIC CONSIDERATIONS

Surveys indicate that the most serious problems resulting from subsidence are depressions or potholes that cause water to stand, and the disruption of drainage patterns to either underground tile or surface drainageways (15). As a result, reduced crop yields and, in some cases, complete crop loss have been reported.

Restoration of land productivity affected by subsidence is accomplished by four main methods:

1. Restoring surface drainage is the most frequent method; it is most commonly accomplished by digging surface drainage ditches.
2. Replacing broken underground tile.
3. Use of mechanical equipment to fill depressions with soil from the surrounding area.
4. Hauling in dirt from outside the area to fill depressions.

The soils in Illinois were formed under varying conditions and, therefore, have differences in structure, texture, and potential agricultural yields. Of those areas where coal mining is practiced, north central, east central, and central Illinois have the highest potential corn yields under a high level of management, which most successful farm operators now use. West central Illinois has moderately favorable productivity indexes and

potential corn yields under high level management. Southwestern and southern Illinois soils are less productive, and potential corn yields under a high level of management are, therefore, lower than in the other areas (15).

Poor drainage, whether natural or subsidence induced, will affect the timing and opportunity to perform field tillage and planting operations. Delayed spring planting caused by standing water and wet conditions affects plant growth and crop yield; the extent of such impacts has not yet been determined and will require carefully planned observation and analyses. The final evaluation must include both analysis of the effect on annual yields of major crops and the long-term effect on productivity, and the conservation of soil for use by future generations.

Case examples from Illinois described by Guither (15) show crop yields affected by subsidence ranging from 30- to 100-pct reduction in productivity, depending on the location, topography, and rainfall. An interesting note is that in dry years subsided areas may show no impact as little water collects in the depressions. In fact, in dry areas subsidence-induced depressions may produce more than the surrounding area as they do collect moisture. However, in wet years the depression may remain saturated for the entire growing season and totally eliminate crop production.

The costs of reduced land productivity due to mined land subsidence fall basically into two categories: (1) loss of crop productivity and (2) restoration of damaged land to full productivity. There are additional costs to the community such as damage to public facilities, loss in land values, and loss in taxes.

It seems highly probable that, with the advance of high-extraction coal mining in Illinois, the total amount of surface land affected by subsidence will become significant. Detailed analysis now in progress by the State should establish that amount and evaluate crop production loss due to subsidence associated with underground coal mining techniques.

BUREAU OF MINES AND STATE OF ILLINOIS SUBSIDENCE RESEARCH PROGRAM

Cooperative research between the Bureau and the State of Illinois (16) has been initiated to develop techniques of reliable subsidence prediction for high-extraction retreat and longwall mining methods. If successful, such prediction techniques will allow the use of high-extraction mining, which will cause planned, immediate subsidence with minimal impact on surface crop productivity. The Bureau is currently involved in four areas: (1) analysis of geomechanical and subsidence profile data, (2) prediction and modeling of subsidence, (3) assessment of stability problems in mines, and (4) characterization of structural foundation response to subsidence.

The Bureau is cooperating with the State of Illinois in developing data bases for geomechanical properties of the overburden and subsidence profile characteristics. The Bureau-sponsored research program will increase the data base available in the State for analyzing overburden response to high-extraction mining methods by monitoring the overburden and ground surface over an existing high-extraction mine.

The development of prediction and modeling techniques will visually demonstrate what may happen under various mining and geological conditions in Illinois coal mines. Models can be excellent guides, and the ability to predict hydrological changes caused by surface elevation changes is necessary for the planning of mining operations to minimize impacts on surface drainage patterns.

A computer program is being developed to model subsidence-related changes in slopes and elevations. Initially scheduled to be based on previously monitored longwall panels from southern Illinois, the final model will incorporate data from a 10-mi² area to ensure that all programs in the model are functional. Ideally, the final model will select a compromise between (1) no mining with no subsidence and (2) full-extraction mining with maximum subsidence, such that positive drainage is maintained or reestablished after the surface has been

stabilized and maximum crop production is assured.

A research program is underway to monitor seven subsidence sags that have developed during the past 20 yr over a room-and-pillar mine. These sags have affected surface drainage. The sags probably resulted from subsidence due to pillar punching and time-related roof and floor squeeze, and depressions gradually developed on the surface. The research is designed to determine why abandoned room-and-pillar mines in Illinois become unstable, collapse, and create subsidence-related problems such as impacted surface drainage.

Another Bureau-sponsored research project, at Southern Illinois University at Carbondale, is designed to assist in the characterization of pillar strength and stability problems for improvements in the design of planned and unplanned subsidence. Combined with State-sponsored work of the physical and mechanical properties of floor materials, this research will aid in pillar stability analysis for mine design.

Mine planners using high-extraction methods need to know how long subsidence-related movement will continue so that repairs to structures and farmland will not be made until the area is stable. The Bureau is investigating the duration of ground movement from high-extraction mining in Illinois. Generally, when coal is extracted from an area in Illinois, caving and surface movement happen rapidly. Most existing data indicate that 95 pct of movement occurs within 90 days of mining, but because the caved rock continues to settle and compact under its own weight, small movements may occur for years after the mining front has passed. Acceptable limits of residual movement need to be established such that needed restoration can take place as quickly as possible.

The University of Illinois at Urbana-Champaign (17) is researching the effects of planned subsidence resulting from high-extraction underground coal mining on subsequent agricultural suitability

and productivity. Mined and unmined lands are being surveyed, and the effects of subsidence on crop growth will be determined.

Future Bureau and Bureau-sponsored research will include developing subsidence prediction methods for the mining and geologic conditions in Illinois. More accurate analytical methods need to be developed, and these must be based on an

understanding of how geological factors affect the migration of strata movements from the mine itself to the resulting surface profile. Subsidence prediction along with more complete geomechanical data must ultimately form the basis for mine and mining plan guidelines that will minimize the impacts of subsidence on the ability of overlying prime farmlands to sustain maximum crop production.

SUMMARY AND CONCLUSIONS

Generally, the Illinois Coal Basin is a broad, spoon-shaped trough of sediments containing anticlinal folds of gentle slope with less than 200 ft of relief. The topography ranges from flat to rolling with glacial till soils ranging from 600-ft deep in the northern and central parts to less than 50-ft deep in southern Illinois.

Most of the mapped coal reserves are in the middle portion of the Pennsylvanian System, underlying the southern two-thirds of the State. Overlying shales are generally 20- to 40- ft thick, and underlying clays are only 2- to 5- ft thick. Ground water is contained in the glacial overburden to a level of 2 to 15 ft below the surface and is highly dependent on surface recharge.

Retreat room-and-pillar and longwall are the two high-extraction underground coal mining methods used in Illinois. Both methods are high recovery systems, and their resulting subsidence and surface profiles can be similar.

Subsidence from underground mining in western Pennsylvania disturbs the overlying ground water by opening fractures in the strata and allowing the water to drain into lower strata and ultimately into the mine. After mining, the overlying structure generally heals with time due to settling and compression, and the ground water level is restored by recharge. The water may or may not reach its former level, depending on the new hydrologic balance.

The potential effects of high-extraction mining subsidence on the ground water in Illinois may be somewhat different. The shale layers above the caving zone and the overlying strata are

flexible and tend to sag over the mined-out area, with only minor fracturing. If the subsided area quickly heals itself, the ground water in the glacial till may be restored to its former level; and, since the normal level is close to the surface, the new water level may exceed the subsided ground level. The results could then be highly saturated soils and ponding conditions that would severely reduce crop production.

Good plant growth requires well-drained to moderately well-drained soil with good soil moisture consistency and texture. There should be at least 30 in of soil above a hard layer, and the surface slope should be less than 10 pct. Most importantly in Illinois, seasonal water tables need to be far enough below the ground surface to allow for good root development.

Erosion is the single process that is most destructive to a soil, as it reduces the soil's productivity by removing nutrients and structure that are contained in the upper soil layers. Erosion is mainly dependent on the soil unit, rainfall, and topography. Of those three factors, only topography (i.e., slope) is controllable and directly affected by mine subsidence. High-extraction underground coal mining subsidence in Illinois generally results in minor slope changes and, therefore, negligible changes in the erosion potential. The major impact is on drainage, and where the topography is extremely flat, a small change in slope may result in a change from positive to negative drainage. As long as positive drainage is maintained, however, a small change in slope should not severely affect crop production.

The Bureau and the State of Illinois are cooperating on research to develop techniques for reliable subsidence prediction for high-extraction retreat room-and-pillar and longwall mining methods in Illinois. Successful prediction techniques will allow the use of

high-extraction mining methods, resulting in planned, immediate subsidence with minimal impact on surface crop production. The cooperative program will result in mining plans that maximize both coal production and subsequent crop production in the prime farmland areas.

REFERENCES

1. Guither, H. D., J. Hines, and R. Bauer. The Economic Effects of Underground Mining Upon Land Used for Illinois Agriculture (Univ. IL at Urbana-Champaign, Dep. Agric. Econ., and the IL State Geol. Surv.) IL Dep. Ener. and Nat. Resour., Doc. 85/01, Feb. 1985, 185 pp.
2. O'Rourke, T. D., and S. M. Turner. Longwall Subsidence Patterns: A Review of Observed Movements, Controlling Parameters, and Empirical Relationships. Sch. Civil and Environ. Eng., Cornell Univ., Ithaca, NY, Geotech. Eng. Rep. 79-6, Nov. 1979, 82 pp.
3. Olson, G. W. Soils and the Environment, A Guide to Soil Surveys and Their Applications. Dowden & Culver, Inc., 1981, 178 pp.
4. U.S. Department of Agriculture. Soil Survey Manual. Agric. Handbook 18, 1962 (reissued), 503 pp.
5. _____. Guide for Interpreting Engineering Uses of Soils. 1971, 87 pp.
6. Sarkar, P. K., O. W. Bidwell, and L. F. Marcus. Selection of Characteristics for Numerical Classification of Soils. Proc. Soil Sci. Soc. America, v. 30, 1966, pp. 269-272.
7. Peng, S. S., and S. L. Cheng. Prediction of Surface Subsidence Profile Due to Underground Coal Mining. Dep. Min. Eng., Coll. Min. and Ener. Res., WV Univ., Tech. Rep. TR 80-5, Dec. 1980, 46 pp.
8. Bauer, R. A., and S. R. Hunt. Profile, Strain, and Time Characteristics of Subsidence From Coal Mining in Illinois. Paper in Proceedings of Workshop on Surface Subsidence Due to Underground Mining, ed. by S. S. Peng and M. Harthill (Morgantown, WV, Nov. 30-Dec. 2, 1981). Dep. Miner. Eng., Coll. Miner. and Ener. Resour., WV Univ., Mar. 1982, pp. 207-218.
9. Janes, J. R. A Demonstration of Longwall Mining (contract J0333949, Old Ben Coal Co.). BuMines OFR 86-85, 1983, v. 1, 105 pp.; v. 2 (appendix), 372 pp.
10. Pennington, D., J. G. Hill, G. J. Burgdorf, and D. R. Price. Effects of Longwall Mine Subsidence on Overlying Aquifers in Western Pennsylvania (contract J0199063, SMC Martin Inc.). BuMines OFR 142-84, 1984, 149 pp.; NTIS PB 84-236710.
11. Singh, M. M., and S. Bhattacharya. Proposed Criteria for Assessing Subsidence Damage to Renewable Resource Lands. Soc. Min. Eng. AIME preprint 84-391, 1984, 7 pp.
12. U.S. Department of Agriculture. Land-Capability Classification. Agric. Handbook 210, 1973, 21 pp.
13. Guernsey, L., P. Mausel, and J. Oliver. An Overview of the Factors Involved in the Restoration of Mined Prime Farmland. Committee on Interior and Insular Affairs, Subcommittee on Energy and the Environment. 96th Congr., 1st sess., serial 96-4, Mar. 1979, pp. 577-580.
14. Darmody, R. G., I. J. Jansen, and N. T. Patterson. Effects on High Extraction Coal Mine-Induced Subsidence on Crop Production. Prelim. Rep. to the Illinois Mine Subsidence Research Program Advisory Committee, Aug. 29, 1985, 3 pp.; available from R. G. Darmody, Dep. Agronomy, Univ. IL at Urbana-Champaign.

15. Guither, H. D. The Economic Effects of Subsidence From Underground Coal Mines on Agricultural Land in Illinois (contract H0222010, Univ. IL at Urbana-Champaign). BuMines OFR 186-84, 1984, 60 pp.; NTIS PB 85-109296.

16. Wade, L. V., and J. J. Olson. Productivity, Safety, and Environment--A Coordinated Approach for Improving Coal Mining Technology. Paper in Proceedings

of Ninety-Third Annual Meeting of the Illinois Mining Institute (Springfield, IL, Oct. 31-Nov. 1, 1985). IL Min. Inst., 1986, pp. 21-44.

17. Bauer, R. A. (Illinois State Geological Survey Division). Private communication, Nov. 4, 1985; available upon request from David L. Veith, BuMines, Minneapolis, MN.



U.S. Department of the Interior
Bureau of Mines—Prod. and Distr.
Cochrans Mill Road
P.O. Box 18070
Pittsburgh, Pa. 15236

AN EQUAL OPPORTUNITY EMPLOYER

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, \$300

- ☐ Do not wish to receive this material, please remove from your mailing list.
- ☐ Address change. Please correct as indicated.





LIBRARY OF CONGRESS



0 002 953 939 A